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The Impacts of Land-use/cover Change on Loktak Lake Water Quality in North-Eastern Region, India

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Abstract: The present study was designed to understand the long-term impacts of land-use/cover change on hydrology and nutrient dynamics of Loktak Lake in Manipur. The major land-use/cover changes are the expansion of built-up land, open forest land, aqua ponds/water bodies and wetland. There was increase in built-up land by 0.80%, open forest by 9.39% and water bodies by 1.31%. The surface inflow from rivers/streams accounts 52% of the total inflow into the lake. The annual average sediment input into the lake was estimated as 650,000 metric tonnes. The nutrient (DO, free CO_2, chloride, TDS, BOD and phosphate phosphorous, etc.) levels of the lake varied between seasons and sites. High intensity of fertilizer usage in the agricultural fields and practice of fish farming contribute significantly to water quality deterioration in the lake. The highly polluted rivers (Nambul and Nambol) also finally discharge pollutants in the lake. Today, Loktak Lake has been placed on the informal list of threatened Ramsar sites of the world. Only a concerted effort on the part of official agencies, professionals, NGOs and the local communities to comprehend the complexities of this delicately balanced, biologically rich wetland ecosystem, and take appropriate action, can save Loktak Lake from demise.

Key words: Land-use/cover change, physicochemical properties, shifting cultivation, Manipur, Ramsar site, wetland.

Introduction

Anthropogenic activity is one of the major driving forces leading to changes in land-use/cover characteristics and subsequently hydrologic processes, specifically through the large-scale conversion of forests to other land-uses (Rai et al., 1994; Rai, 1995; Jain et al., 2000; Mao and Cherkauer, 2009). Substantial changes in land-use/cover have occurred over north-eastern part of India in the past few decades with the shortening of *jhum cycle*, spread of settlement and increasing use of land resources for agriculture and economic development. Shifting cultivation, also known as "Slash and Burn" or "Swidden agriculture" and as "Jhum cultivation" in north-east India, where it is a predominant activity for the majority of the population, is often described as an inefficient, destructive practice, which contributes to deforestation and lowland sedimentation (Sillitoe, 1998). The jhum system is aimed at maintaining high crop diversity, achieving food security through utilizing locally available organic resources for sustained yields and cooperation/social integration on a local scale (Spencer, 1966; Borthakur et al., 1978). Reducing the jhum cycle during recent years has put pressure on resources and thus the productivity of land degradation, increased levels of soil erosion, hydrological imbalances and forest degradation—all of which have caused reductions in yields and insecurity of food sources (Toky and Ramakrishnan, 1981). Understanding the characteristics of hydrological processes and regime change is important for driving the solutions to rational use of the lake water and limiting the environmental degradation in the region.

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Several earlier studies have focused on ecological, wetland ecosystem management, rather than on the catchment's scale hydrologic impacts of land-use/cover change. Singh (1989) studied wetland ecosystem management perspective of fish, wildlife and environment in Loktak Lake. Bhatia (1979) studied ecological study of Loktak Lake. Singh and Shymananda (1990) studied management of Loktak Lake. There is a broad understanding of land-use/cover change but their associations with the hydro-ecological consequences are not understood properly. So, there is a need to understand the relationship of these changes and those problems. Therefore, in view of this, the present study is focused on impact of land-use/cover change on water chemistry of Loktak Lake of Manipur, which needs immediate conservation.

The Loktak Lake

Loktak Lake, the largest natural lake in north-eastern India, occupies the southern part of Manipur valley and runs north–south. The beauty of Loktak Lake has earned it the name "Jewel of Switzerland" of India. Its biological richness, and uniqueness of habitat, has resulted in its designation as a "Wetland of International Importance" under the Ramsar Convention, a distinction it shares with just five other lakes in India. The lake is famous for its floating mats of vegetation locally called *phumdi*, and for being the only refuge of the endangered *Sangai* (Manipur brow-antlered deer) which is closer to extinction.

The Loktak Lake is situated 38 km south of Imphal, the capital city of Manipur. It lies between longitudes 93º46′ to 95º55′ E and latitudes 24º25′ to 24º42′ N (Figure 1).

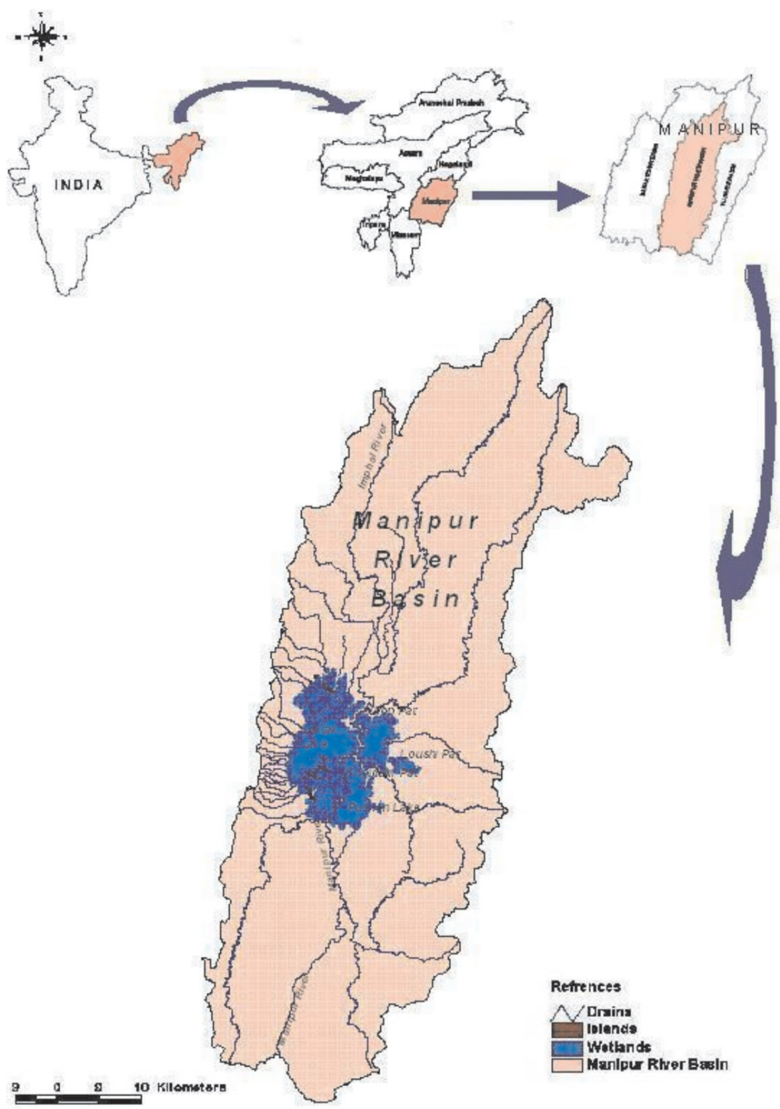

Figure 1: Location of Loktak Lake.

The lake, along with its surrounding swamps (locally called *pats*) is an integral part of the floodplain of Imphal River. The oval-shaped Manipur Valley (height: 746–798 m asl), bounded by mountains rising 2000–3000 m above sea level, along with the Imphal River and its tributaries (Iril, Thoubal, Heirok, Khunga and Chakpi), and other streams (Nambul, Nambol and Ningthoukhong) that pour their silt-laden water directly into Loktak Lake. Morphometric data are summarized in Table 1.

Three different zones, i.e., Northern, Central and Southern, were considered for the sampling site. Six sampling sites, two each in every zone, all in the lake periphery except one site (Site IG, which is an island). The three disturbed sites were selected in the study are Moirang (Site MO); Khathinungei (Site KI) and Mayang Imphal (Site MI) whereas the comparatively undisturbed sites are Hayel (Site HA), Khordak (Site KH) and Ithing (Site IG) (Figure 2).

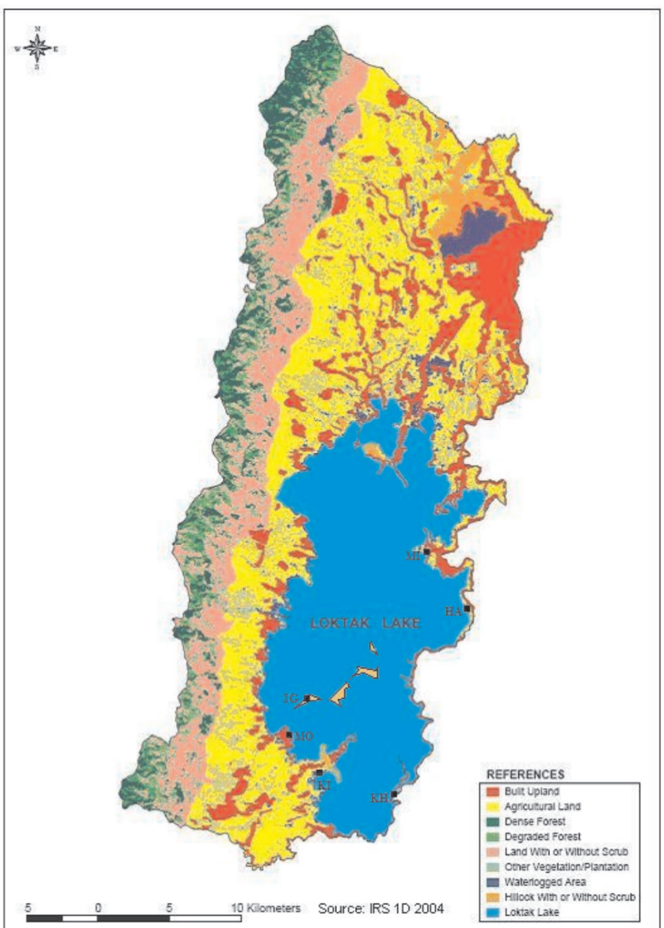

Figure 2: Map showing land-use/cover and water quality sampling sites viz., MO = Moirang; KI = Khathinungei; MI = Mayang Imphal; HA = Hayal; KH = Khordak; and IG = Ithing of Loktak Lake.

Table 1: Morphometry of Loktak Lake

Maximum length (L)	26 km
Maximum breadth (B)	13 km
Shore line length (L)	126 km
Orientation	North–South
Surface area	287 km^2
Area covered by *Phoomdis*	107 km^2
Area covered by islands	17.2 km^2
Area covered by encroached land of fish farm, paddy field, etc.	89.3 km^2
Area of open water	73.5 km^2
Mean breadth	11.04 km
Shoreline development	2.10
Total volume of water	550.21M m^3
Maximum depth (Zm)	4.58 m
Mean depth (V:A)	1.92 m
Mean depth : Maximum depth (Z : Zm)	0.42
Development of volume	1.26
Area of catchment	980 km^2
Surface area : Catchment area	0.293
Index of lake permanence	1.92

Materials and Methods

Land-use/cover Change

The data for land-use/cover of Loktak Lake catchment have been derived from secondary sources. The temporal land-use/cover data of Loktak Lake catchment of 1990 and 2004 including structural component data of 2004 have been obtained from Loktak Development Authority and Manipur Remote Sensing Application Centre, Imphal. The land-use/cover map has been prepared by using high resolution data like IKONOS, for some area and merge data of 2.5 m resolution using LISS-III and PAN data. By comparing the temporal land-use data of 1990 and 2004, major land-use/cover changes that occur between the two periods were obtained. Intensive field investigations were carried out for verification.

Water Quality Analysis

Water samples from six sites were collected in replicate and made a composite sample during 2008–09 for chemical analysis. These samples were collected between 9 and 11 hours from 10–15 cm depth in sterilized polyethylene bottles of one litre and were transported to the laboratory within 12 hours of collection. Water temperature was measured at mid-day (between 1200 and 1300 hours) at all the sites. The samples were collected seasonally, i.e., rainy, winter and summer.

Some parameters such as pH and EC were measured before filtering the samples. The pH of the water were determined with a digital pH meter (Elico, Model L1-120) using a double function reference electrode. The electrical conductivity (EC) (µmoh/cm) of samples was determined with a digital conductivity meter (Systronics, Model 306). Remaining samples were filtered and stored in a refrigerator. All analyses were completed within ten days following standard method (Eaton et al., 1995). Total alkalinity as $CaCO_3$ was measured gravimetrically. Dissolved oxygen (DO) was estimated by the azide modification method, phosphate-phosphorous (PO_4-P) was estimated by stannous chloride method and chloride by argentometric method (Eaton et al., 1995). The free carbon-dioxide was measured following method given by Eaton et al. (1995). Biological oxygen demand (BOD) was estimated by titration method (Eaton et al., 1995) measuring the differences of oxygen concentration by azide modification method between the initial sample and incubating the sample for five days at 20 ºC in dark. Total dissolved solid was estimated by evaporating the filtered sample and weighing the residue in an evaporating disc at temperature 550 ºC in a muffle furnace.

The data were prepared and processed in SPSS 15.0 software in window XP. Statistical analysis between source, seasons and water quality and their interaction was based, on analysis of variance (ANOVA). This statistical analysis is depicting a significant correlation among different sources. Chemical parameters of water quality varies in different sources with changing seasons.

Results

Land-use/cover Change

A detailed land-use/cover inventory was developed to assess the current status of the lake catchment and presented in Table 2 and Figure 2. The land-use/cover pattern in the lake catchment as a whole showed about 13.99% and 14.85% area under built-up land in 1990 and 2004, respectively. Agriculture is the main occupation of both the people living in the hill and valley area of Loktak Lake. The total agriculture land in the valley accounts for 36.28% and 35.62% in 1990 and 2004, respectively. On the other hand, shifting cultivation or *Jhum* cultivation is a very popular practice in the hill catchments. This type of cultivation is also known as slash and burn cultivation and account for 3.01% and 1.74% in 1990 and 2004, respectively. The total forest land in the lake catchment covered more than 40% canopy and accounts for 1.43% and 0.56% of the total area of the catchment in 1990 and 2004, respectively. The area where canopy cover is less than 10% is considered as degraded forest and its area accounts for 8.95% and 3.35% of the total area of the catchment in 1990 and 2004, respectively. Scrub land is observed mostly in the periphery of dense forest. The total areas under this class accounts for 9.35% and 5.80% in 1990 and 2004, respectively. Open forest represents the forest areas which were earlier deforested and presently natural regeneration is going on. The total areas under this class accounts for 0.37% and 9.76% in 1990 and 2004, respectively. The area under marshy/swampy class

Table 2: Area under different land-use/cover in Loktak Lake

Land use classes	*Area*				*Variations (%)*
	1990		*2004*		*(1990–2004)*
	(ha)	*(%)*	*(ha)*	*(%)*	
Built-up land	14,558	13.99	15,448	14.85	0.86
Agricultural land	37,735	36.28	37,055	35.62	-0.66
Shifting cultivation	3,131	3.01	1,811	1.74	-1.27
Dense forest	1,493	1.43	586	0.56	-0.89
Open forest	391	0.37	10,160	9.76	9.39
Degraded forest	9,312	8.95	3,514	3.35	-5.58
Scrub forest	9,732	9.35	6,042	5.80	-3.55
Marshy/swampy land	631	0.60	509	0.48	-0.12
Hill/hillocks	755	0.72	705	0.67	-0.05
Aqua-ponds/water bodies	974	0.93	2,331	2.24	1.31
Wetland	25,312	24.33	25,839	24.84	0.51
TOTAL	104,000	100	104,000	100	-

Source: Loktak Development Authority (LDA) accounts about 0.60% and 0.84%, whereas hills/hillocks about 0.72% and 0.67% in 1990 and 2004, respectively. Area under water bodies such as ponds, reservoirs, rivers and aquaculture ponds are clubbed together and accounts for 0.93% and 2.24% in 1990 and 2004, respectively. The total area under wetlands accounts for 24.33% and 24.84% in 1990 and 2004, respectively (Table 2).

During the 15-year period, the major land-use/cover changes are the expansion of built up area, open forest, aqua-ponds/water bodies and wetland (Table 2). There was increase in built up land up by 0.86% which was the result of rapid urbanization in the Loktak catchment. The urban population in the catchment has grown at an annual rate of 3.5% during 1991–2001. The open forest area increased by 9.39% in 2004 and decrease in degraded forest area by 5.58% shows that the activities of afforestation programme have been taken up by LDA for catchment treatment that reduces the shifting cultivation area by 1.27% and ultimately led to the process of natural regeneration in the catchment area. However, there was decrease in dense forest area from 1990 to 2004 by 0.89% which was the effect of past deforestation that need some span of years to regenerate again. The evidence of regeneration is very much clear from the open forest area which increased up to 9.39% in 2004. There has been an increase in the water bodies/aqua-ponds by 1.31%. This is mainly due to conversion of agriculture and marshy/swampy land into aqua-ponds as a result of inundation after the construction of Ithai barrage. This process led to the decrease of agriculture land and marshy/swampy land by 0.66% and 0.12%, respectively (Table 2).

Sedimentation

Loktak Lake is gradually silting and the major contributor is sediment from the surrounding catchment. The annual average sediment input into the lake is estimated as 650,000 metric tonnes. Western catchment accounts for 65% of the total sediment inflow into the lake and the rest 35% from the link channels. The high amount of sediment from the western catchment is mainly due to land-use/cover change and *jhum* cultivation, etc. Out of 45 micro-watersheds of the western catchment, Thongjarok yields the maximum sediment load of 58 t/ha and the minimum of 2 t/ha by Merakhong (Table 3). Sedimentation has been observed in the peripheral areas of the lake especially at the mouth of the western streams and link channels, resulting in the reduction in the water holding capacity of the lake, and resulting in flooding in the peripheral areas. It has been observed that the silting rates have increased by 34.44% during 1993 to 2003 and by 69.94% during 1967 to 2003. High sediment deposition in the lake turns the lake turbid and deteriorating water quality.

Physicochemical Characteristics

The data reveals that pH of lake water ranges from 6.27 to 8.50. The lake water in different sites is severely affected and has also become considerably vulnerable to pollution with a wide range to contamination. Dissolved oxygen concentration ranges from 6.80 to 9.32 (mg/l) and electrical conductivity in between 98 and 530 (µmoh/cm). Concentration of chloride ranges from 8 to 30 (mg/l) and phosphate-phosphorous concentrations fluctuate in between 0.002 and 0.260 (mg/l).

Seasonal variation in water quality characteristics of Loktak Lake have been analysed in detail. Most of the selected parameters reflected the seasonal pattern showing higher values in the rainy season. The pH was recorded highest at Site MI during summer season and lowest at Site KI during winter seasons. Analysis of variance showed that the pH varied significantly at sites and seasons but their interaction was not significant (Figure 3).

Water temperature ranged from 9.7 °C and 29.4 °C in the temporal cycle, highest during summer and lowest

Table 3: Sediment yield during 2000–01

Rivers	*Discharge (MCM)*	*Sediment load (t)*	*Area (ha)*	*Sediment yield (t/ha)*	*N (t/yr)*	*P (t/yr)*	*K (t/yr)*
Potsangbam	22	20,752.18	1,928.00	10.80	27	6	20
Awang khujairok	9	4,229.91	843.40	5.00	54	841	
Thongjarok	30	133,440.83	2,302.30	58.00	57	9	45
Merakhong	-	12,097.18	5,947.20	2.00	-	-	-
Nambol	104	65,911.02	9,540.00	6.90	243	34	198
Nambul	161	50,204.90	19,893.00	2.50	2,338	270	2,081

Source: Loktak Development Authority (LDA)

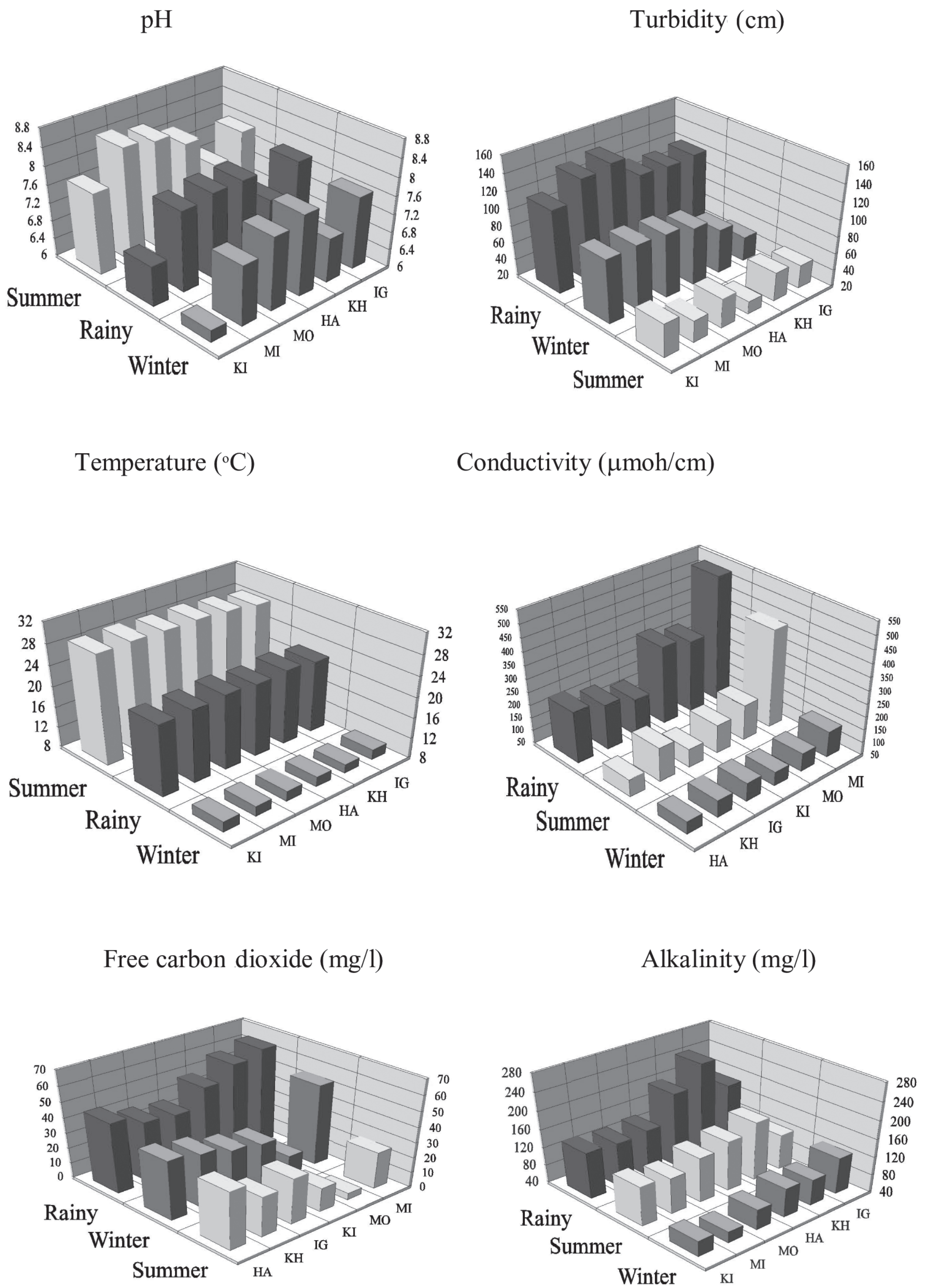

Figure 3: Seasonal variation in pH, transparency, temperature, conductivity, free carbon dioxide and alkalinity of water at six sites in the Loktak Lake.

ANOVA: **pH Site $F^{5,36}$ = 11.67, *P*< 0.001; Season $F^{2,36}$ = 16.9, *P*< 0.001; Site × Season $F^{10,36}$ = 1.43, *P* = NS. Transparency Site $F^{5,36}$ = 22.9, *P*< 0.001; Season $F^{2,36}$ = 1990, *P*< 0.001; Site × Season $F^{10,36}$ = 54, *P*< 0.001, LSD(0.05) = 2.6. Temperature Site $F^{5,36}$ = 0.123, *P* = NS; Season $F^{2,36}$ = 3535, *P*< 0.001; Site × Season $F^{10,36}$ = 1.04, *P* = NS. Conductivity Site $F^{5,36}$ = 5195, *P*< 0.001; Season $F^{2,36}$ = 14598, *P*< 0.001; Site × Season $F^{10,36}$ = 1064, *P*< 0.001, LSD(0.05) = 2.4. Free carbon-dioxide Site $F^{5,36}$ = 45.5, *P*< 0.001; Season $F^{2,36}$ = 279, *P*< 0.001; Site × Season $F^{10,36}$ = 31.9, *P*< 0.001, LSD(0.05) = 2.4. Alkalinity Site $F^{5,36}$ = 450, *P*< 0.001; Season $F^{2,3}$ = 2732 *P*< 0.001; Site × Season $F^{10,36}$ = 116.4, *P*< 0.001, LSD (0.05) = 2.4.**

during winter. Variation in temperature was significant between seasons but not between sites. The turbidity of the lake at various sites ranged from 35 cm to 145 cm. The highest turbidity (145 cm) was recorded in the rainy season at Site MO (Figure 3). Variation in turbidity was significant between sites and seasons, and their interaction was also found to be significant (LSD (0.05) = 1.9) (Figure 3).

Alkalinity was lowest during winter at all sites**.** The total alkalinity varied significantly among the sites and seasons and their interaction was significant (LSD (0.05) = 2.4) (Figure 3). Electrical conductivity showed marked variation among seasons and sites with higher values ranging from 194 to 530 µ moh/cm during rainy season, followed by summer (116 to 428 µ moh/cm) and winter (98 to 150 µ moh/cm). It varied significantly among the sites and seasons, and their interactions was significant. (LSD (0.05) = 2.4) (Figure 3). Free carbon dioxide was highest in rainy season and ranged from 4.4 to 63.3 mg/l at various sites of the lake across the season. It varied significantly among the sites and seasons, and their interactions was also significant (LSD (0.05) = 2.4) (Figure 3).

Dissolved oxygen concentration range from 6.8 to 9.32 mg/l. Oxygen content of the bottom layers is lower compared to the surface, indicating the eutrophic nature of the lake ecosystem. It shows inverse relationship with free carbon dioxide showing its peak in summer months. It varied significantly between sites and seasons and their interaction was also found significant (LSD (0.05) = 0.3) (Figure 4).

Chloride concentration was highest in rainy season in all the sites and ranged from 8 to 30 mg/l. It varied significantly among the sites and seasons and their interaction was significant (LSD (0.05) = 4.1) (Figure 4). Phosphate-phosphorus concentrations fluctuate between 0.21 mg/l to 0.86 mg/l at various sites of the lake. Overall high amount of phosphate-phosphorous was observed during rainy season. Its concentration increased considerably in rainy season; may be attributed to the inflow of nutrients from the catchment area where fertilizers are extremely used for agriculture. It varied significantly among the sites and seasons, and their interaction was also significant (LSD (0.05) = 0.03) (Figure 4).

Total dissolved solid was recorded higher during rainy season at all sites and low during winter season. It varied from 52.7 to 480 mg/l and recorded highest at disturbed sites (360 to 480 mg/l). It varied significantly between sites and seasons, and their interaction was also significant (LSD (0.05) = 2.2) (Figure 4). Biological oxygen demand was observed high in rainy season and low during winter season at all the sites. It ranged from 0.4 to 2.98 mg/l and varied significantly among the sites and seasons, and their interaction was also significant (LSD (0.05) = 0.18) (Figure 4).

Discussion

Loktak Lake suffers from both natural and cultural eutrophication, which is indirectly the result of land-use/cover change. A large amount of fertilizer residues are washed down the lake from its periphery paddy fields during the rainy season and accelerate pollution in the lake. The high silt contents that are brought down into the lake by the feeder streams and from jhumming prone catchment areas have silted up the lake bottom, thereby decreasing its water holding capacity. Changes in the pH of water may be the result of various biological activities (Gupta et al., 1996). If the water body is neither highly alkaline nor highly acidic, the pH of water is generally governed by the carbon dioxide-bicarbonate-carbonate system (Hutchison, 1975). The high value of pH during summer in the lake possibly resulted from increased photosynthesis utilizing free CO_2 present in water as reported by other workers (Raven, 1970; King, 1970; Goldman, 1972; Farrell et al., 1979). pH showed a positive correlation with temperature, conductivity, alkalinity, chloride, dissolved oxygen, BOD and TDS and negative correlation with turbidity and free carbon dioxide and total phosphorus (Table 4). The water temperature recorded higher during summer is basically important for its effects in the biological reactions of the organism. Temperature showed positive correlation with conductivity, alkalinity, dissolved oxygen, chloride, BOD and TDS and negative correlation with turbidity, free carbon dioxide and total phosphorous (Table 4).

Alkalinity refers to the amount of carbonates, bicarbonates and hydroxide ions and is commonly found in the form of carbonates of sodium, calcium and magnesium (Zajic, 1971). The higher concentration of alkalinity value and free carbon dioxide in the present study is similar with the report of Pandey and Kumar (1995). Alkalinity showed a positive correlation with all the parameters except total phosphorus (Table 4). The high values of conductivity especially at disturbed sites during rainy season are associated with higher inflow from the surroundings. Our results are supported by the report of Plass (1975) that lakes receiving direct runoff from watershed contain significant amounts of mineral precipitates that increase conductivity. Conductivity showed positive correlation with all the parameters

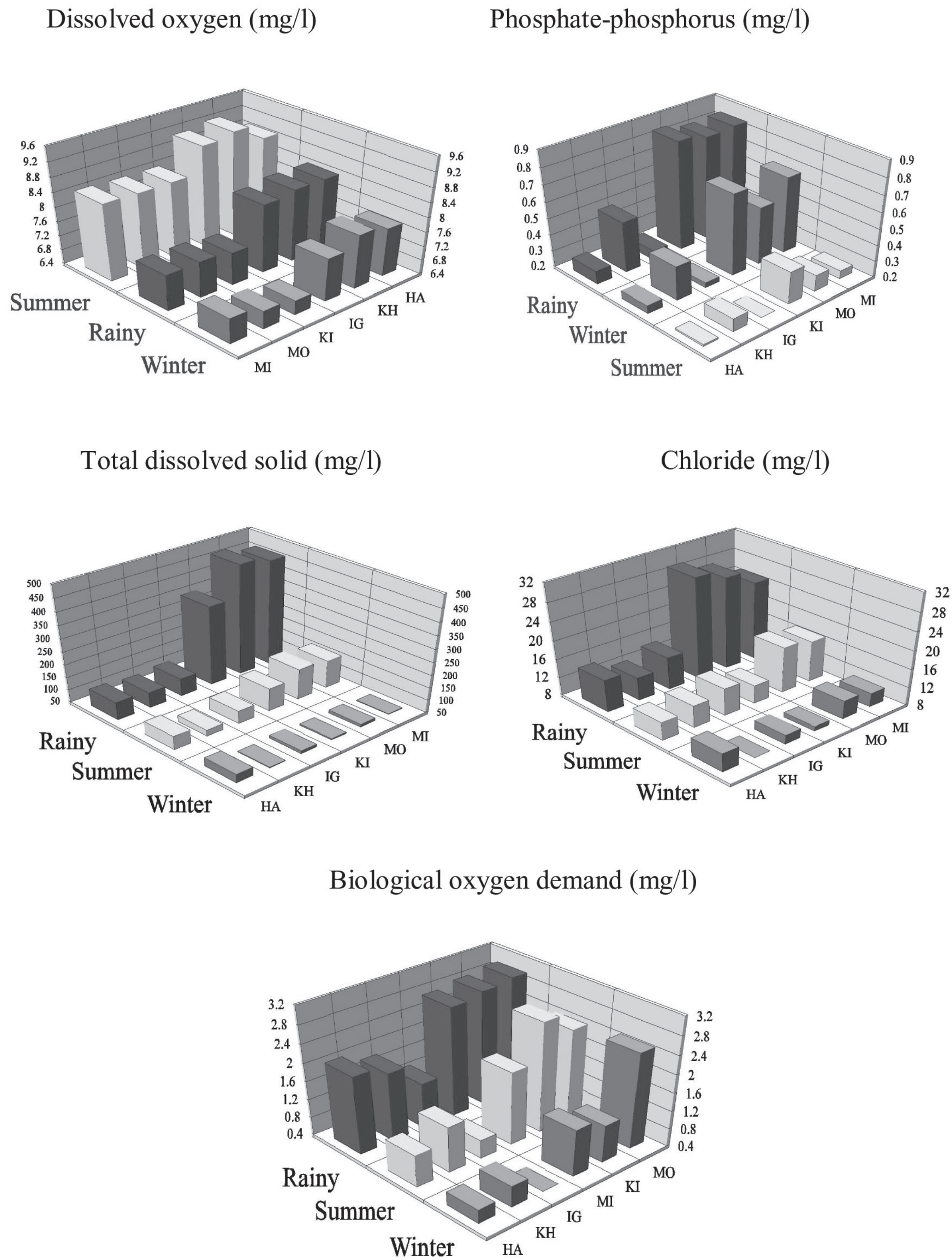

Figure 4: Seasonal variation in dissolved oxygen, total phosphorus, total dissolved solids, chloride and biological oxygen demand of water at six sites in the Loktak Lake.

ANOVA: **Dissolved oxygen Site $F^{5,36} = 15.8$, $P < 0.001$; Season $F^{2,36} = 49.3$, $P < 0.001$; Site × Season $F^{10,36} = 9.6$, $P < 0.001$, LSD(0.05) = 0.3. Phosphate-phosphorus Site $F^{5,36} = 154$, $P < 0.001$; Season $F^{2,36} = 247$, $P < 0.001$; Site × Season $F^{10,36} = 22.9$, $P < 0.001$, LSD(0.05) = 0.03. Total Dissolved Solid Site $F^{5,36} = 4335, < 0.001$; Season $F^{2,36} = 20981$, $P < 0.001$; Site × Season $F^{10,36} = 2702$, $P < 0.001$, LSD(0.05) = 2.2. Chloride Site $F^{5,36} = 24.3$, $P < 0.001$; Season $F^{2,36} = 136.9$, $P < 0.001$; Site × Season $F^{10,36} = 13.7$, $P < 0.001$, LSD(0.05) = 4.1. Biological oxygen demand Site $F^{5,36} = 47.9$, $P < 0.05$; Season $F^{2,36} = 118$, $P < 0.001$; Site × Season $F^{10,36} = 2.7$, $P < 0.05$, LSD(0.05) = 0.18.**

except dissolved oxygen (Table 4). In present study, total dissolved solids had a cyclic pattern of seasonal changes and maximum during rainy season and minimum in winter. Johnson (1988) observed that total dissolved solid proportionately enhanced the electrical conductance in water and ran parallel to each other. The correlation between conductivity values and total dissolved solids (0.803) is similar with the above views. TDS showed positive correlation with all the parameters except dissolved oxygen (Table 4).

During the study period, water turbidity was found higher during the rainy season. It might be due to the high silt content of the water carried down into the lake by the feeder rivers and streams from the catchment areas. Such similar results were reported by Zutshi et al. (1980). Turbidity showed positive correlation with conductivity, alkalinity, free carbon dioxide, chloride, total phosphorus, BOD and TDS and negative correlation with temperature and pH. The most important source of chlorides in the waters is the discharge of domestic sewage. During present investigation, chloride concentration was found maximum during rainy season in all the six sites and on the contrary it was low during winter season. High chloride values were observed from the sites where anthropogenic pressure is maximum, which is related with animal wastes from cattle grazing and sewage disposed off by the household residing in the lake catchment. Excess of chloride over 5.5 mg/l in water was associated with contamination from animal organic matter (Khulbe, 1992; Jain et al., 1999). In freshwater environment, high chloride values are mainly due to pollution of human and animal waste (Trivedy and Goel, 1984). It is suggested that higher level of chloride in water is an index of pollution (Munawar, 1970). Site IG, which is comparatively undisturbed site, showed slightly higher values of chloride which is attributed to sewage inflow directly by inhabitants of biomass dwellers from the *phoom sang*/floating huts. The chloride shows positive correlation with all other parameters except dissolved oxygen (Table 4).

Phosphorous is an important factor in ecological studies and often regarded as a limiting element in water ecosystem (Hecky and Kilhan, 1988). Main source of phosphorous in the lake was from domestic sewage, detergents and agricultural runoff. The high values of phosphate–phosphorus was recorded at disturbed site as compared to undisturbed site during rainy season, which might be due to rain draining into the lake with the nutrient-rich soil deposited from the catchment areas of lake by its feeder streams and rivers. The Sites MO and KH show higher values as to their contemporary sites which receive direct hill slope overland flow during rainy season. Total phosphorus showed positive correlation with conductivity, turbidity, free carbon dioxide, chloride, BOD and TDS (Table 4).

High level of free carbon dioxide during rainy season was observed which may be attributed to its influx through rainwater in the form of carbonic acid. This is in conformity with the observation of Chakraborty et al. (1959), Mathew (1978) and Mansoori et al. (1995). Lower level of free carbon dioxide during summer months might be due to high photosynthetic activity utilizing free carbon dioxide. This view is also supported by Yousuf et al. (1996). Free carbon dioxide showed positive correlation with turbidity, conductivity, alkalinity, chloride, total phosphorus, BOD and TDS and negative correlation with pH, temperature and dissolved oxygen (Table 4). The dissolved oxygen was generally recorded higher at undisturbed sites which may be due to less anthropogenic pressure and high photosynthetic

Table 4: Pearson's correlation coefficient for physicochemical characteristics of Loktak Lake, 2009 (*n*=54, d.f =18)

Parameters	*pH*	*Temperature*	*Turbidity*	*Conductivity*	*Alkalinity*	*Dissolved oxygen*	*Free CO_2*	*Chloride*	*Phosphate-phosphorus*	*BOD*	*TDS*
pH	—	0.561	–0.29	0.252	0.185	0.495	–0.193	0.184	–0.495	0.167	0.163
Temperature		—	–0.252	0.375	0.528	0.771	–0.160	0.305	–0.260	0.476	0.305
Turbidity			—	0.465	0.266	–0.552	0.678	0.541	0.717	0.499	0.584
Conductivity				—	0.274	–0.087	0.477	0.781	0.470	0.715	0.803
Alkalinity					—	0.515	0.181	0.237	–0.175	0.294	0.148
DO						—	–0.305	–0.162	–0.727	-0.106	–0.225
Free CO_2							—	0.480	0.534	0.219	0.562
Chloride								—	0.583	0.775	0.937
Phosphate–phosphorus									—	0.584	0.653
BOD										—	0.776
TDS											—

activity. The low dissolved oxygen during the winter season is probably caused by decreased penetrating power of solar radiation due to decreased transparency and turbulence that resulted in the reduction of photosynthesis. Our results are consistent with Khulbe (1992). The dissolved oxygen showed negative correlation with all other parameters except pH, temperature and alkalinity (Table 4).

The presence of BOD in the Loktak Lake may be from polluted Nambul River and also from the domestic waste from local areas including from several huts lying inside the lake on the *phoomsdis*. High value of biological oxygen demand during rainy season might be due to high organic loads along with the rain runoff from the catchment area of the lake. Pandey and Kumar (1995) have also reported the same view for the lake Nainital of Kumaon Himalaya. BOD and TDS showed positive correlation with all the other parameters except dissolved oxygen (Table 4).

The data based on the water quality is an indicator of the water quality at the time of sampling. However, regardless of the high variation of the water quality, the results obtained can be representative of the spatial variation of the water quality throughout a wide range. Only a concentrated effort on the part of official agencies, professionals, NGOs and the local communities themselves can save Loktak Lake from demise.

Conclusion

Recognizing the ecological, socio-economic as well as aesthetic importance of Loktak Lake, and its rapidly deteriorating water quality, it is utmost need to protect the lake. The lake water is not fit for direct drinking without treatment but can be used for irrigation purposes. A comparative analysis of water quality of different sites indicates high levels of pollution in the densely populated sites as compared to that of less populated sites because dissolved oxygen was low and bio-chemical oxygen demand, chloride, phosphate-phosphorous, total dissolved solids including nutrient levels were higher in the densely populated sites. High levels of phosphorus and nitrogen during the monsoon may be attributed to the inflow of nutrients from the catchment area where fertilizers are extensively used for agriculture. It also indicates that out of the three zones (i.e. northern, central and southern zones) of the lake, the northern and southern zones show high levels of pollution. High intensity of fertilizer usage in the agricultural fields and practice of fish farming contribute significantly to water quality deterioration in the northern zone. The highly polluted rivers (like Nambul and Nambol rivers) also finally discharge pollutants in this zone. Southern zone is polluted due to flow of all the pollutants finally in this zone and their accumulation due to poor flushing. So, while taking up any water management plan of Loktak ecosystem the highly populated sites of the northern and southern zone should be given priority at any cost.

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